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REVIEW AND ASSESSMENT OF THE BASELINE DATA FOR THE MUSQUASH ESTUARY MARINE PROTECTED AREA MONITORING INDICATORS

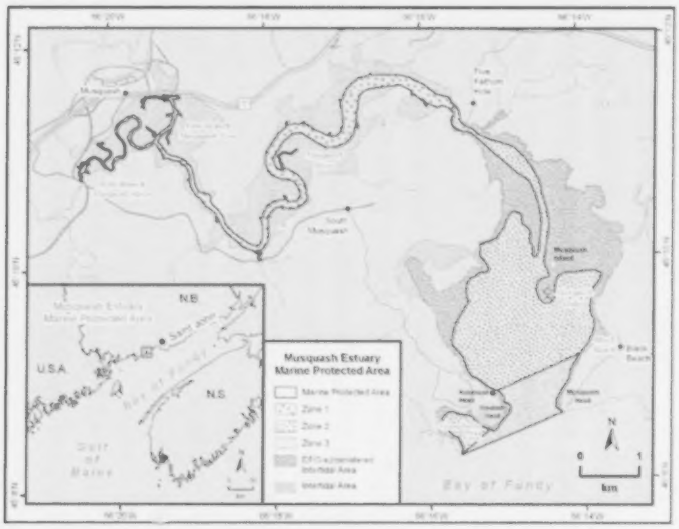

Figure 1. The Musquash Estuary Marine Protected Area (MPA) and Administered Intertidal Area (AIA) managed by Fisheries and Oceans Canada (DFO).

Context:

The Musquash Estuary is located in southwest New Brunswick (Figure 1). Its large size, expansive salt marshes, and relatively undisturbed natural condition make it unique among estuaries in the Bay of Fundy. The estuary exhibits a diverse number of habitat types and related biological communities. On December 14, 2006, the lands and waters in the Musquash Estuary up to mean low water level were designated a Marine Protected Area (MPA) through regulations pursuant to Canada's Oceans Act. The Oceans Act, however, do not apply to the lands and waters between mean low and mean high water levels, and, as a result, the Musquash Estuary MPA Regulations do not apply to the intertidal area administered by Fisheries and Oceans Canada (DFO) . This area, referred to as the Administered Intertidal Area (AIA), was transferred from the Province of New Brunswick to DFO and is managed, as part of the MPA, pursuant to the Fisheries Act, Federal Real Property and Federal Immoveables Act, and other applicable legislation (e.g., New Brunswick Trespass Act, etc.). Throughout this document, reference to the MPA includes both the MPA and AIA.

In support of the Health of the Oceans Initiative (HOTO), DFO Science is to provide advice on indicators, strategies, and protocols for monitoring the individual conservation objectives of MPAs established pursuant to the Oceans Act. The selection of indicators as well as the strategies and protocols for the collection and analysis of monitoring data must be scientifically defensible.

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Canada

In 2010, DFO Science proposed the Musquash Estuary MPA Ecosystem Monitoring Framework (DFO, 2011) that identified15 indicators to monitor the conservation objectives of the MPA; however, it was recognized that a lack of baseline data exists for many aspects of the Musquash Estuary. As baseline data improves, strategies, protocols, and indicators may be refined or dropped. The proposed indicators, strategies, and protocols were not intended to address non-biological aspects of monitoring (e.g., social, economic, or historical), with the exception of the threats presented by human activities that are consistent with the Musquash Estuary MPA Regulations.

Research and monitoring activities have, and continue to be, undertaken in the Musquash Estuary to improve understanding of ecosystem structure and function, although no systematic monitoring program within the MPA ecosystem has been implemented. A Maritimes Region Science Peer Review was conducted on June 25-27, 2013, to review a summary of current monitoring and research activities completed in the Musquash Estuary. The scope of the discussion was to assess whether collected data provides an adequate baseline for on-going monitoring of the MPA and whether the indicators proposed in the monitoring framework are likely to be effective in assessing ecosystem change in light of the new baseline data collected. The meeting also reviewed the indicators, strategies, and protocols proposed in the 2010 Musquash Estuary MPA Ecosystem Monitoring Framework in an effort to refine and clarify the information based on the research data acquired since 2010. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The scope of this Science Advisory Report is to assess whether collected data provides an adequate baseline for on-going monitoring of the Musquash Estuary Marine Protected Area (MPA) and Administered Intertidal Area (AIA) boundaries and whether the monitoring indicators are likely to be effective in assessing ecosystem change.
- In 2010, Musquash Estuary MPA Ecosystem Monitoring Framework which proposed 15 indicators to monitor the MPA ecosystem in the context of the Conservation Objectives for the MPA was reviewed. The 2010 framework recommended that research should be conducted to better understand the structure and function of the ecosystem to inform future monitoring and management decisions for the MPA (DFO, 2011). Further, such research would develop baselines for the various indicators, enhance understanding of protocols required to monitor various indicators in the Musquash Estuary, as well as refine the indicators to enhance their utility for monitoring to ensure the conservation objectives are being maintained.
- Data collected from research and monitoring activities related to benthic biodiversity, physical oceanography, sediment dynamics and trace metals, fish community assemblages, bird population surveys, and human threats were reviewed.
- The indicators and protocols used to monitor and describe the physical characteristics of the environment (e.g., freshwater input, temperature (T), salinity (S), oxygen (O), and chlorophyll (Chl)) over the past three years were appropriate. However, additional sampling is required to produce baseline values for these indicators over a range of spatial and temporal scales.
- Data collected to date provides an adequate baseline for sedimentation rate. Additionally, the trace metal data from both surficial samples and from core samples represent a reliable baseline dataset. Although the coverage does not encompass the entire marine section of the MPA, all data to date are at background values. It is recommended that a surficial grain size survey be completed in the MPA, with the top 0.5 cm of the seabed analyzed for grain size which can then be used as a baseline to assess seabed change

with time. The development of a coupled hydrodynamic – sediment transport model is also recommended to assess and model the physical drivers of the ecosystem.

- The available data is not sufficient to determine baseline values for phytoplankton in the Musquash MPA. In addition, the significant amount of sampling required to capture trends and establish a baseline within the MPA is not considered feasible.
- The data collected and analyzed to date provide adequate baseline values for species richness and dominant taxa for the benthic macrofauna in the habitat types sampled. Seasonal baseline values can be determined for the summer sampling period, but further sampling is required for the other sampling periods to delineate natural variation in the winter and fall seasons.
- Results of fish sampling within the estuary provide a comprehensive representation of nearshore fish assemblages at each of the three sites sampled. Baselines values for species assemblages can be determined from collected data; however, this has not been completed to date. If future sampling were completed as a comparison to baseline data, additional sampling would enhance the quality of data and reduce the variability associated with species richness and with catches.
- Key bird species that can function as indicators for monitoring the health of the Musquash MPA ecosystem should include breeding marsh birds, staging migratory shorebirds, and waterfowl. Potential species that could be considered include: Sora Rail, American Bittern, Pied-billed Grebe, Semipalmated Sandpiper, American Black Duck, and Common Eider.
- Although total biomass was identified as an indicator for productivity, measures of biomass have not been collected for indicators within the Musquash MPA due to the intensive sampling effort requirements. Thus, consideration needs to be given to other measures of productivity.
- A reference point was defined as the point that once it is exceeded further management action is triggered. A strategy to determine reference points for indicators was discussed and would require sampling and analysis, as necessary, to determine natural variation around the baseline value for each indicator. The reference point would then be an agreed upon statistical deviation from the baseline distribution (i.e., baseline value plus or minus natural variation). As well, further discussion is needed to determine the acceptable level of sampling frequency required for each indicator to defensibly calculate a statistical deviation from the baseline distribution.
- Two complementary monitoring strategies have been identified and require additional consideration for the Musquash MPA Monitoring Program. First is an intensive sampling period, the duration of which would be dependent on the indicator, every 5-10 years with the goal to understand ecosystem function, determine natural variability, and compare results to previous sampling periods. The second strategy consists of conducting smaller subsets of sampling more frequently (e.g., annually) to maintain an understanding of how key components of the ecosystem are reacting to threats and pressures.

BACKGROUND

Rationale for Assessment

In support of the Health of the Oceans Initiative (HOTO), the Science Branch of Fisheries and Oceans Canada (DFO) was asked to propose scientifically-defensible indicators, strategies, and

protocols for monitoring the conservation objectives of established MPAs that have been designated pursuant to Canada's Oceans Act. The Musquash Estuary MPA Ecosystem Monitorning Framework (Cooper et al. 2011), which consists of 15 monitoring indicators (see Appendix) and a range of protocols and strategies, was reviewed in 2010. It was recommended that research should be conducted to better understand the structure and function of the ecosystem which would inform future monitoring and management decisions for the MPA (DFO 2011). Further, such research would develop baselines for the various indicators, enhance understanding of protocols required to monitor various indicators in the Musquash Estuary, as well as refine the indicators to enhance their utility for monitoring to ensure the conservation objectives are being maintained. While management decisions are currently being undertaken to regulate human activities in the protected area, an understanding of the baseline state of the ecosystem in the estuary is required to determine the success of DFO's management actions.

The science advice outlined in this report reviews whether the research and monitoring activities that have occurred in and around the MPA provide adequate ecological baseline values upon which to base future monitoring activities, and whether the indicators are likely to be effective in assessing ecosystem change in light of the baseline data collected. It also recommends changes to the indicators, protocols and strategies proposed in the 2010 Musquash Estuary MPA Ecosystem Monitoring Framework. The updates to the monitoring framework that have been recommended in this Science Advisory Report will need to be evaluated against fiscal and other considerations, and do not necessarily reflect a final monitoring plan for the MPA.

Conservation Objectives

Conservation objectives for the Musquash Estuary MPA are to ensure that there is no unacceptable reduction or human-caused modification in:

productivity so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species;

biodiversity by maintaining the diversity of individual species, communities, and populations within the different ecotypes; and

habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality.

Assessment of Ecological Data Relevant to the Monitoring Indicators

Data collected from research and monitoring activities pertaining to benthic biodiversity, physical oceanography, sediment dynamics and trace metals, fish community assemblages, and bird population surveys were reviewed in the context of providing baseline values within the MPA ecosystem. Indicators specific to human pressures were discussed and it was noted that no baseline values exist for these indicators. Furthermore, it is recommended that data for these indicators be analyzed annually, where possible, and used where appropriate to help explain changes to the ecological indicators.

Physical Environment

The indicators and protocols used to monitor and describe the physical characteristics of the environment (e.g., freshwater input, temperature (T), salinity (S), oxygen (O), and chlorophyll (Chl) over the past three years were appropriate. However, additional sampling is required to produce baseline values for these indicators over a range of spatial and temporal scales.

The variability of freshwater flow into the estuary is determined by the opening and closing of the dams at the mouths of the east and west rivers that feed the estuary. Thus, 'natural' baseline for freshwater input to the estuary is unlikely to be determined due to the anthropogenic control of the source water. Further work is required to determine how influential freshwater input is to the ecosystem function and structure of the MPA. Thus, it is recommended that monitoring of the river flow via water levels and discharge rates be continued and that discharge curves be developed. It was further suggested that since water levels in the East Branch Musquash River dam are recorded every hour by the New Brunswick Department of Natural Resources, freshwater flow could be calculated from the gate position, water level, and spillway dimensions.

The variability in each of the other physical variables (T, S, O, and Chl) also suggests baselines for these indicators cannot be determined using the existing data, and continued sampling using the same protocols over multiple years is required to capture tidal, seasonal and inter-annual and event variability so trends can be detected. The data collected to date does show the water exchange at a coarse spatial scale, as well as the movement of water masses into and out of the estuary. The data also show that the saline water mass moves back and forth in the estuary due to tidal flows and freshwater inputs; however, the maximum penetration of the saline water into the estuary and its influence on the physical parameters of the habitat and associated biological communities is not known. In addition to the natural fluctuations of the water masses, time series data show episodic events (e.g., storm surge) that can significantly alter the physical characteristics of the water column and hence affect resident communities.

The development of a calibrated model to predict changes to physical parameters and habitat is recommended. Although a detailed grid is completed for the estuary, freshwater flow and other features (e.g., wind influence) have not yet been incorporated within the model. Ongoing activity to complete the calibrated circulation model and it validation with physical data is recommended.

Opportunities to gather physical data through ongoing activities in the estuary, such as the annual Musquash Paddle organized by the Conservation Council of New Brunswick, should continue to be pursued.

Sediment Dynamics

Sediment and bottom core samples were analyzed to determine sedimentation rate, trace metal concentrations, and grain size within the estuary.

Data collected to date provides an adequate baseline for sedimentation rate. Additionally, the trace metal data from both surficial samples and from core samples represent a reliable baseline dataset. Although the coverage does not encompass the entire marine section of the MPA, all data to date are at background values. Any increase above the background level for a metal of interest would necessitate additional monitoring or research to investigate reasons for the increase in trace metal value.

The surficial grain size data from the MPA is incomplete. Although several bottom sediments were collected and grain size distributions were obtained, those samples represent several centimeters (top 5 cm) of the seabed which encompass almost a decade of sedimentation in the MPA. It is recommended that a surficial grain size survey be completed in the MPA, with the top 0.5 cm of the seabed analyzed for grain size which can then be used as a baseline to assess seabed change with time. The development of a coupled hydrodynamic – sediment transport model is also recommended to assess and model the physical drivers of the ecosystem.

Phytoplankton

Minimal phytoplankton sampling has been completed in the Musquash Estuary. In comparison to the other sampling sites in the Bay of Fundy, results from samples collected in Musquash indicate the presence of the same species; however, phytoplankton concentrations in the lower portion of the estuary were very low with even lower concentrations found in the upper estuary where freshwater input is higher. The available data from the few samples that have been collected within the MPA is not sufficient to determine baseline values for phytoplankton in the Musquash Estuary. However, results from the long-term monitoring of inshore sites in the southwestern New Brunswick portion of the Bay of Fundy could be used as a proxy of populations, species composition, and species abundance for the mouth of the Musquash Estuary. It is important to note that phytoplankton concentrations in the Musquash Estuary appear to be representative of other intertidal estuaries.

The long-term phytoplankton monitoring program in the outer Bay of Fundy is labor intensive and requires multiple sampling periods (e.g., twice a week) to detect changes in plankton abundance and composition. This intensive sampling has shown that phytoplankton communities in the area have a significant amount of inter-annual variability. To utilize such an intensive sampling protocol for the MPA would not be feasible.

The development and applications of new technology, such as remote sensing and the use of florescence, is a promising tool for monitoring phytoplankton at the scale of an MPA. However, in the coastal zone, high particle density in the water (e.g., sediments, colored dissolved organic matter, etc.) can result in inaccurate measurements of phytoplankton. Research is continuing to adapt remote sensing tools so that they are more effective in coastal environments.

Benthic Biodiversity

Over the past three years, sampling activities have focused on establishing a baseline for benthic fauna in the MPA, specifically species diversity and abundance, in three different habitat types (or strata): intertidal, subtidal, and narrow channel. The intertidal areas (mudflats) are typically exposed during low tide, the subtidal area is never exposed during low water, and the narrow channel is a natural bathymetric feature that periodically or continuously contains moving water, has a definite bed, and has banks that serve to confine the flow of water. The sampling design, which included the collection of 3 grab samples at 10 stations within each of the 3 strata for 3 sampling periods (winter, summer, fall), has resulted in the collection of a total of 147 benthic sampling grabs over 3 years. Only the summer sampling period was completed for all three years.

Establishing ecological baseline values requires consideration of natural variability; thus multiple measurements over a range of temporal and spatial scales are necessary. The habitat types sampled were limited to the lower portion of the MPA (downstream of Five Fathom Hole to the mouth of the harbour). Additional sampling would be required to characterize the upper portion of the MPA.

The data collected and analyzed to date provide adequate baseline values for species richness and dominant taxa for the benthic macrofauna in the habitat types sampled. Seasonal baseline values can be determined for the summer sampling period, but further sampling is required for the other sampling periods to delineate natural variation in the winter and fall seasons. Spring sampling was not feasible due to the unpredictable timing of the spring freshet. Ongoing monitoring of these indicators will require equivalent sampling effort at appropriate spatial and temporal scales to detect a change against the baseline values. If a less intensive sampling regime is desired, then the probability to detect change will be reduced. An analysis of correlation with other biological, physical and chemical parameters would improve

understanding of the function of the benthic ecosystem components and provide more informative baseline values. Furthermore, simultaneous measurements of these parameters would help explain changes to biodiversity indicators.

Juvenile Fish

Sampling efforts have focused on describing temporal and spatial trends of the near-shore fish community within the Musquash MPA and surrounding areas. Beach seines and fyke nets were used to collect fish twice a month at three sites within the Musquash MPA (Five Fathom Hole, Hepburn Basin, and Black Beach). Samples were also collected at two adjacent sites (Dipper Harbour and Saints Rest Beach). Results of fish sampling within the estuary provide a comprehensive representation of nearshore fish assemblages at each of the three sites sampled. Baselines values for species assemblages can be determined from collected data; however, this has not been completed. If future sampling were completed as a comparison to baseline data, additional sampling would enhance the quality of data and reduce the variability associated with species richness and with catches. The data presented indicate that the Musquash ecosystem is not unique from other similar areas in terms of fish assemblages; thus in addition to a site within the MPA, a control monitoring site should be located outside the MPA to assess for larger scale influences.

Bird Population Surveys

Extensive bird monitoring programs are undertaken by Environment Canada's Canadian Wildlife Service within Atlantic Canada; however, the resolution of these large scale monitoring programs is quite coarse (with sampling units larger than the MPA). Formal analyses to specifically establish potential contributions to MPA monitoring have not been undertaken for many of the resulting datasets. Information within the Coastal Waterfowl Survey database may contain suitable baselines for monitoring, but survey polygons extend beyond the bounds of the MPA. Data within the Eastern Waterfowl Survey are limited and insufficient to confidently provide baseline breeding waterfowl densities within the MPA. The Eider Winter survey may contain suitable baselines for monitoring, but congregations of wintering Common Eider ducks typically occur outside the bounds of the MPA. The Atlantic Canada Shorebird Survey (ACSS) may lead to suitable baselines for monitoring, but lack of existing data gathered within the MPA presently precludes consideration for MPA monitoring purposes at this time. Creation of an ACSS site within the MPA boundary should be considered. Offshore 'pelagic' bird surveys are contingent on accessibility of sites by large ocean-going vessels. No surveys exist within the Musquash MPA. Surveys using Eastern Canada Seabirds at Sea (ECSAS) protocol remain possible, using small vessels, but may not constitute the best option for bird monitoring within MPA bounds.

The Maritimes Marsh Monitoring Program (MMMP), a volunteer-based pilot program, implemented by Bird Studies Canada provides potential for collecting information within the MPA and adjacent intertidal lands. Standardized survey protocols are implemented at point locations in several habitat types, e.g., wet meadow, shallow marsh, deep marsh, coastal wetlands (i.e., tidal salt marsh) and forested wetlands, with 17 survey locations located in the MPA. The MMMP is in year two of a pilot program, thus, no baselines have yet been established for the MPA; however, there is potential to build a dataset which could evaluate local (e.g., watershed, MPA) scale changes in wetland bird populations.

Key bird species that can function as indicators for monitoring the health of the Musquash MPA ecosystem should include breeding marsh birds, staging migratory shorebirds, and waterfowl. Potential species that could be considered include: Sora Rail, American Bittern, Pied-billed Grebe, Semipalmated Sandpiper, American Black Duck, and Common Eider.

Recommended Changes to Monitoring Framework

Many of the proposed indicators in the Musquash MPA Monitoring Framework are broad in scope, which makes it difficult to determine accurate and defensible indicator values. Indicators should be more clearly articulated and focused on ecosystem components that can be assessed effectively and efficiently. The research and monitoring data presented above reflects the level of effort that can be sustained with current resources. Many of the recommended changes below attempt to make indicators more accurate and explicit, rather than propose adding or deleting indicators (Table 1).

Productivity

Key species across trophic levels, as opposed to ecotypes, need to be identified based on available data, thus identifying key or dominant species from the benthic macrofauna, juvenile fish, birds, and marine plants is recommended. Although total biomass was identified as an indicator for productivity, measures of biomass have not been collected for indicators within the Musquash MPA due to the intensive sampling effort requirements. Thus, consideration needs to be given to other measures of productivity. For example, marine plants spatial coverage may be an appropriate measure for marine plant productivity.

The indicator "Abundance of juvenile fish within the estuary" should be removed from the list of indicators or added as a sub-indicator to "Total biomass and spatial distribution of species in each trophic level" as the former is considered to be integrated within the latter.

The routine intensive sampling effort associated with determining phytoplankton concentration is not feasible within an MPA monitoring program. Thus, other methods associated with estimating productivity of phytoplankton (e.g., advances in remote sensing in coastal areas) should continue to be explored. Otherwise, it is unlikely that this indicator would form part of the MPA monitoring program.

It is recommended that the name of the indicator "Commercial and recreational fishery landings" be changed to "Commercial and recreational catch per unit effort (CPUE)" as CPUE is considered a more useful measure of productivity.

Consistent with the indicators related to biodiversity and habitat, a reference point was defined as the point that once it is exceeded further management action is triggered. A strategy to determine reference points for indicators was discussed and would require sampling and analysis, as necessary, to determine natural variation around the baseline value for each indicator. The reference point would be an agreed upon statistical deviation from the baseline distribution (i.e., baseline value plus or minus natural variation). As well, further discussion is needed to determine the acceptable level of sampling frequency required for each indicator to defensibly calculate a statistical deviation from the baseline distribution.

Also consistent with the indicators related to biodiversity and habitat, two complementary monitoring strategies have been identified and require additional consideration for the Musquash MPA Monitoring Program. First is an intensive sampling period, the duration of which would be dependent on the indicator, every 5-10 years with the goal to understand ecosystem function, determine natural variability, and compare results to previous sampling periods. The second strategy consists of conducting smaller subsets of sampling more frequently (e.g., annually) to maintain an understanding of how key components of the ecosystem are reacting to threats and pressures.

Additionally, an intensive sampling regime over the first couple of years, as opposed to ad hoc sampling, would establish natural variability within the ecosystem and allow for the development of multi-year monitoring plans. Since management plans for MPAs are reviewed every 5 years,

it is recommended that monitoring data and strategies be reviewed at similar time scales so that any adjustments can inform future management plans.

Biodiversity

Current sampling efforts have collected data on specific groups within trophic levels (e.g., benthic macrofauna, juvenile fish, and birds); however, little data has been collected on other trophic levels, such as marine plants. Research and monitoring efforts should continue where possible to collect baseline data for species within other trophic levels. However, it is recognized that the intensive sampling effort required for sampling all species in each trophic level within each ecotype and the abundance of keystone species within the Musquash MPA is unfeasible.

The name of the indicator "By-catch number, size, age and sex per impacted species" should be changed to "By-catch number per impacted species" as it is unlikely information pertaining to size, age and sex of fish species will be collected during sampling.

It was recognised that there is no known data for the indicator "Number of species at risk within each ecotype" except for birds, of which there are approximately four species, and these should be monitored. Since the intent is for no species loss, species at risk are more vulnerable and; therefore, should be closely monitored.

Habitat

A baseline of total area and location of each ecotype within the estuary, and the proportion and frequency that it is disturbed or lost, could be established through the analysis of aerial, multibeam, and/or LiDAR data that has been collected but not yet analysed.

Determining contaminant concentrations within the estuary is expensive and it is, therefore, recommended that contaminant sampling and analysis be completed when a potential threat is identified.

Table 1. Linkages between conservation objectives and proposed indicators, reference points, monitoring strategies, and monitoring frequencies. An alpha-numeric designation has been assigned for each indicator based on its conservation objective (P–productivity, B–biodiversity, H–habitat). The designations are used to link monitoring strategies and protocols with the general objectives and indicators that are listed in this table. Updated from DFO (2011).

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
Productivity so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species.	Total biomass and spatial distribution of species in each trophic level **(P1).** • Abundance of juvenile fish within the estuary.	To be determined through baseline measurement.	Survey of species within each trophic level through standardized per area sampling such as transect or quadrats. Survey of juvenile fish species in the estuary using beach seines and/or fyke nets.	To be determined
	Commercial and recreational fishing catch per unit effort (CPUE) **(P2).**	To be determined through baseline measurement.	Survey of landings by fishery and species that occur in and adjacent to the MPA, if available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary).	Annual review
Biodiversity by maintaining the diversity of individual species, communities, and populations within the different ecotypes.	Number of exotic species within each ecotype, relative to exotic species in region **(B1).**	To be determined through baseline measurement.	Survey of exotic species within each ecotype, and estimate of exotic species in region through standardized per area sampling such as transect or quadrats (visual surveys where applicable).	To be determined
	Number of species at risk within each ecotype **(B2).**	To be determined through baseline measurement.	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable).	To be determined
	By-catch number per impacted species **(B3).**	To be determined through baseline measurement and review of historical fishery records, if available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary).	Survey of by-catch number of captured individuals per fishery .	Annual review

Table 1. Cont'd

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
Habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality.	Total area and location of each ecotype within the estuary, and the proportion and frequency that it is disturbed or lost **(H1).**	To be determined through baseline measurement.	Map area distribution of each ecotype within the estuary using aerial photographs and GIS software.	To be determined
	Total area and location within estuary of species that provide biogenic structure (e.g. marsh and rockweed) **(H2).**	To be determined through baseline measurement.	Map area distribution that supports species that provide biogenic structure.	To be determined
	Hydrodynamic and sediment regime within the estuary (e.g. sediment infilling) **(H3).**	To be determined through baseline measurement.	Field sampling coupled with hydrodynamic and sediment models that predict the deposition/erosion of sediment, as well as the hydrodynamic regime.	To be determined
	Degree of human induced habitat perturbation or loss **(H4)**.	To be determined through baseline measurement.	Survey of shoreline activities such as construction and dumping.	To be determined
	Temperature and salinity within the estuary **(H5).**	To be determined through baseline measurement and records from NB Power.	Survey of temperature and salinity within estuary.	To be determined
	Nutrient concentrations within the estuary **(H6).**	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels.	Survey of nutrient concentrations within estuary (dissolved oxygen, silicon, iron, carbon, nitrogen, and phosphorus).	To be determined
	Contaminant concentrations within the estuary **(H7).**	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels.	Survey of contaminant concentrations within bottom sediment and water column (dissolved and particulate bound trace metals and organics).	To be determined

*CCME – Canadian Council of Ministers of the Environment

Sources of Uncertainty

Sources of uncertainty exist when attempting to understand the functioning of a complex marine ecosystem, as well as understanding the potential impacts that anthropogenic activities may have on an ecosystem's natural processes and variability. In terms of monitoring the Musquash Estuary MPA, the following sources of uncertainty currently exist:

- Whether the indicators proposed and their respective protocols and strategies for monitoring will be effective in detecting a quantifiable change beyond natural variability in the ecosystem structure and function in the context of the conservation objectives.
- Whether management decisions will be based on the results from one indicator or whether the results from multiple indicators are required to elicit a management response. If multiple indicators are required, some discussions are required to package indicators that are responsive to priority pressures.
- There are some indicators for which no sampling or monitoring activities have been initiated to date and there are no future plans to commence. There will be gaps if these indicators are not monitored, which will impact the ability to determine if conservation objectives are achieved.
- Implementing the monitoring program requires on-going resources, and securing such resources is required.

Knowledge Gaps

There remain significant knowledge gaps in understanding the functioning of the Musquash MPA ecosystem, including the linkages among species groups, the goods and services provided by the ecosystem, and the impacts of physical environmental parameters on biological communities.

In addition, for many of the indicators proposed in the framework, there is a lack of data to determine the baseline conditions and the natural variability surrounding such baselines. Thus, these indicators have not yet been assessed for their utility within a monitoring program.

There is potential for the use of remote sensing technologies for monitoring sediments, colourdissolved organic matter (CDOM), and phytoplankton at a broad scale in the estuary, and efforts are continuing to research its utility.

CONCLUSIONS

A review of the 2010 Musquash Estuary MPA Ecosystem Monitoring Framework, which proposed fifteen indicators to monitor the MPA ecosystem in the context of the Conservation Objectives for the MPA, recommended that research should be conducted to better understand the structure and function of the ecosystem which would inform future monitoring and management decisions for the MPA (DFO 2011). Further, such research would develop baselines for the various indicators, enhance understanding of protocols required to monitor various indicators in the Musquash Estuary, as well as refine the indicators to enhance their utility for monitoring to ensure the conservation objectives are being maintained.

Data relevant to establishing baseline data for the indicators proposed in the Musquash Estuary MPA Monitoring Framework were reviewed and assessed. Collected ecological data focused on benthic biodiversity, physical oceanography, sediment dynamics and trace metals, fish community assemblages, and bird population surveys. Human threats were discussed however; no baseline values exist for these indicators. Indicators specific to human pressures

were discussed and it was noted that no baseline values exist for these indicators. Furthermore, it is recommended that data for these indicators be analyzed annually, where possible, and used where appropriate to help explain changes to the ecological indicators.

The data presented for species richness and dominant taxa for benthic macrofauna in specific habitat types, near shore juvenile fish species assemblages, as well as trace metal concentrations were sufficient to determine baseline values. However, additional data collection is required to capture spatial and temporal variability trends that are needed to determine baseline values for water column physical properties (i.e., temperature, salinity, oxygen, and chlorophyll), freshwater input, phytoplankton concentrations, species richness and abundance of bird communities, and surficial grain size of sediment. There remain indicators for which there are no or limited data available and no on-going sampling efforts to determine baseline values and the natural variability surrounding such baselines. These indicators have not yet been assessed for their utility within a monitoring program.

Many of the proposed indicators are broad in scope and should be clearly articulated and focused on ecosystem components that can be assessed effectively and efficiently. The recommended changes to the monitoring framework attempt to make indicators more accurate and explicit, rather than propose additions or deletion.

OTHER CONSIDERATIONS

An effective governance structure is critical for MPA management and would facilitate how monitoring data is integrated within management decisions. Such a governance structure ensures the best use of expertise, coordination between managers and science advisors, and facilitates a systematic approach to the implementation and evaluation of monitoring indicators and results in a timely manner.

A concerted effort also is required to integrate the various data streams that are being generated from various monitoring activities in the Musquash Estuary by DFO and external partners. Coordination is required to ensure data collection for the various indicators is occurring at comparable temporal and spatial scales. Intensive sampling over longer periods, as opposed to annual sampling, can allow for a more thorough evaluation of spatial and temporal trends within the MPA, thus additional consideration should be given to sampling protocols.

In addition, data management is an essential component of a successful monitoring program. Further thought is required as to the best means of securing long-term data management, such that data accessibility and database design facilitate the sharing, assessment, and reporting of monitoring data relevant to the management of the MPA. In practice, the success of monitoring to evaluate the conservation objectives for the MPA will be dependent on the availability of resources that permit monitoring at an appropriate scale and resolution.

SOURCES OF INFORMATION

This Science Advisory Report is from the 25 to 27 June 2013 Review of the Musquash Estuary Marine Protected Area (MPA) Monitoring Data: Part 2 - Assessment. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Cooper, J.A., K.J. Curran, R. Singh, B. Chang, and F.H. Page. 2011. Musquash Estuary: A proposed monitoring framework for the Marine Protected Area (MPA) and Intertidal Area Administered (AIA) by Fisheries and Oceans Canada. DFO. Can. Sci. Advis. Sec. Res. Doc. 2011/055.

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APPENDIX

Table A1. Linkages between conservation objectives and proposed indicators, reference points, monitoring strategies, and monitoring frequencies. An alpha-numeric designation has been assigned for each indicator based on its conservation objective (P–productivity, B–biodiversity, H–habitat). The designations are used to link monitoring strategies and protocols with the general objectives and indicators that are listed in this table.

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
Productivity so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species.	Total biomass and spatial distribution of species in each trophic level within each ecotype **(P1)**.	To be determined through baseline measurement.	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats.	To be determined
	Abundance of juvenile fish within the estuary **(P2)**.	To be determined through baseline measurement.	Survey of juvenile fish species in the estuary using beach seines and/or fyke nets.	To be determined
	Phytoplankton concentration within the estuary **(P3)**.	To be determined through baseline measurement.	Survey of phytoplankton concentration within the estuary, including chlorophyll-a.	To be determined
	Commercial and recreational fishery landings **(P4)**.	To be determined through baseline measurement.	Survey of landings by fishery and species that occur in and adjacent to the MPA, if available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary).	Annual review
Biodiversity by maintaining the diversity of individual species, communities, and populations within the different ecotypes.	Number of species in each trophic level within each ecotype, and the abundance of keystone and/or dominant species **(B1)**.	To be determined through baseline measurement.	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable).	To be determined
	Number of exotic species within each ecotype, relative to exotic species in region **(B2)**.	To be determined through baseline measurement.	Survey of exotic species within each ecotype, and estimate of exotic species in region through standardized per area sampling such as transect or quadrats (visual surveys where applicable).	To be determined
	Number of species at risk within each ecotype **(B3)**.	To be determined through baseline measurement.	Survey of species within each ecotype through standardized per area sampling such as transect or quadrats (visual surveys where applicable).	To be determined
	By-catch number, size, age, and sex per impacted species **(B4)**.	To be determined through baseline measurement and review of historical fishery records, if available (note: data must be at appropriate resolution to assess landings in and adjacent to the Musquash Estuary).	Survey of by-catch number, size, age, and sex of captured individuals per fishery.	Annual review

Table 1. Cont'd

Conservation Objectives	Indicator	Reference Point	Monitoring Strategy	Monitoring Frequency
Habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality.	Total area and location of each ecotype within the estuary, and the proportion and frequency that it is disturbed or lost **(H1)**.	To be determined through baseline measurement.	Map area distribution of each ecotype within the estuary using aerial photographs and GIS software.	To be determined
	Total area and location within estuary of species that provide biogenic structure (e.g. marsh and rockweed) **(H2)**.	To be determined through baseline measurement.	Map area distribution that supports species that provide biogenic structure.	To be determined
	Hydrodynamic and sediment regime within the estuary (e.g. sediment infilling) **(H3)**.	To be determined through baseline measurement.	Field sampling coupled with hydrodynamic and sediment models that predict the deposition/erosion of sediment, as well as the hydrodynamic regime.	To be determined
	Degree of human induced habitat perturbation or loss **(H4)**.	To be determined through baseline measurement.	Survey of shoreline activities such as construction and dumping.	To be determined
	Temperature and salinity within the estuary **(H5)**.	To be determined through baseline measurement and records from NB Power.	Survey of temperature and salinity within estuary.	To be determined
	Nutrient concentrations within the estuary **(H6)**.	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels.	Survey of nutrient concentrations within estuary (dissolved oxygen, silicon, iron, carbon, nitrogen, and phosphorus).	To be determined
	Contaminant concentrations within the estuary **(H7)**.	To be determined through baseline measurement, as well as CCME* and literature-based guideline levels.	Survey of contaminant concentrations within bottom sediment and water column (dissolved and particulate bound trace metals and organics).	To be determined

*CCME – Canadian Council of Ministers of the Environment

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